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Levelized Cost of Energy Calculation for Energy Storage Systems

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LCOE

- The levelized cost of energy (LCOE) is defined as
  - the net present value of the entire cost of electricity generated over the lifetime of a generation asset divided by the total generated energy,

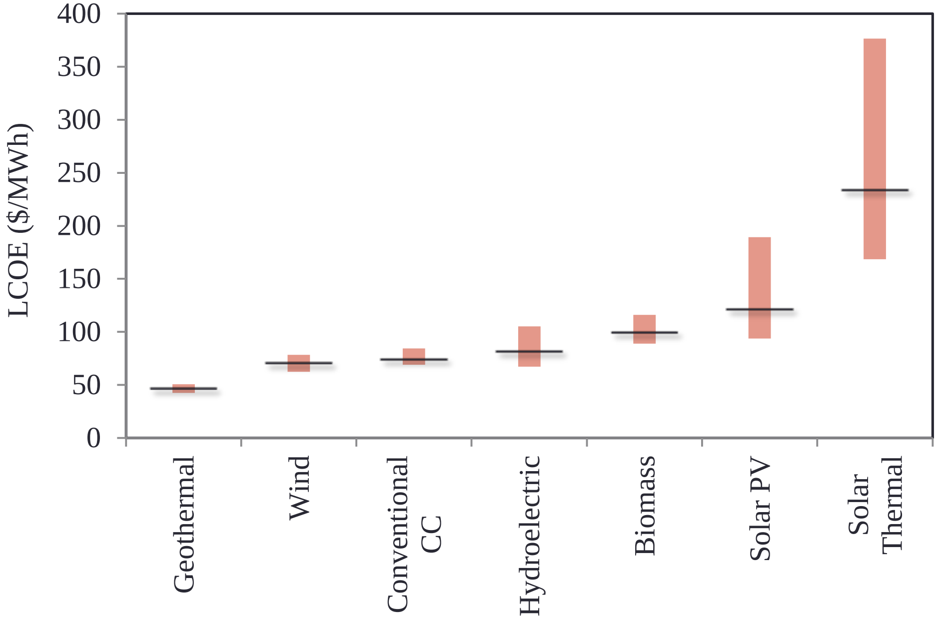
  Or

  - the sum of investment costs, production cost, as well as the operation and maintenance (O&M) costs divided by the total energy produced over the lifetime of the asset.

- The LCOE can be used to effectively determine if a generation unit is economically viable to be installed and to further investigate if the deployed technology cost can break-even over the lifetime of the project.

Advantages

- The LCOE enables cost comparison of the generation technology with the grid price at the point of connection to the grid.
  - This comparison determines the economic viability of a generation technology at a specific point in the electricity grid while further displaying the grid parity.
  - Grid parity is defined as the point at which a DG can produce electricity for customers with the price equal to or less than utility rates.



Significance of Energy Storage

- Energy arbitrage
  - store energy when the price is low and supply the loads when the price is high
- Renewable support
  - capture highly volatile and intermittent renewable generation
- Islanding
  - support when the supply of power from the utility grid is interrupted
- Reactive power support
  - correct power factor and/or adjust voltage levels

→These benefits come at the expense of the high capital cost of the energy storage.

→It is extremely important to determine its LCOE and further enable an easy and efficient comparison with other technologies from an economic viability perspective.

LCOE Calculation

- A simplified and general method for calculating LCOE of a generation unit is as follows:

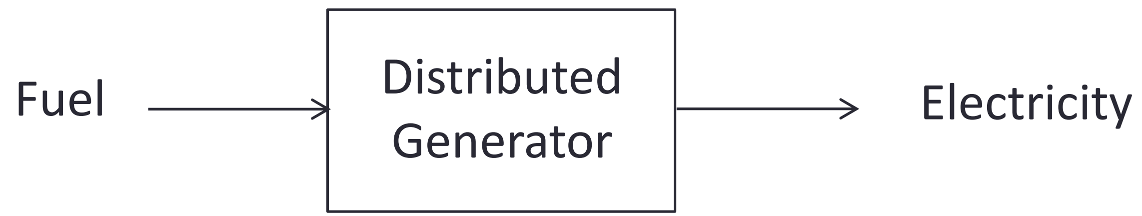
$$LCOE = \frac{(I+F)+(C_F+V)}{E}$$

- I is the investment cost ($)
- F is the fixed O&M cost ($)
- V is the variable O&M cost ($)
- C_F is the unit generation cost ($)
- E is the total energy produced in the project lifetime (MWh)

- The net present costs are obtained using discount rate d which appears as coefficients $1/(1+d)^{t-1}$ for each year t.

LCOE Calculation For The Energy Storage

- The mentioned cost and energy terms to calculate LCOE can be directly determined for DGs.
  - The production cost term represents the cost of purchasing fuel and generating electricity
  - The energy term represents the total amount of energy that is produced over the unit lifetime based on the purchased and consumed fuel.



- For energy storage, however, all of the cost terms cannot be directly determined:
  - for the production cost it is not clear whether the charging cost should be considered, or the discharging benefit, or a combination of both.
  - The same issue exists for the energy as it is not clear whether to consider the charged energy, the discharged energy or net energy.

- To make these determinations, we use an analogy between energy storage and the discussed DG in terms of inputs and outputs:

- The formulation for calculating the LCOE of the energy storage can therefore be written as follows:

$$LCOE = \frac{(CC^{P}\,P^{\max} + CC^{E}\,E^{\max}) + \sum_{t} \rho\, E_{t}^{ch}}{\sum_{t} E_{t}^{dch}}$$

CC^P is the annualized investment cost for power ($/MW)
CC^E is the annualized investment cost for energy ($/MWh)
P^{max} is the rated power (MW)
E^{max} is the rated energy (MWh)
ρ is the utility grid price ($/MWh)
E_t^{ch} is the daily charged energy (MWh)
E_t^{dch} is the daily discharged energy (MWh)
t is the index of days in a year, i.e., t=1,…,365

- We can further simplify the equation based on the following assumptions:
  - There is a linear relationship between the rated power and the rated energy based on the number of charging hours, T^{ch}. This relationship can be written as $E^{\max} = P^{\max} \times T^{ch}$.
  - The energy storage is fully charged and discharged each day. Considering the roundtrip efficiency η, the relationship between the daily charged and discharged power can be obtained as $E_t^{dch} = \eta \times E_t^{ch}$.
  - The daily charged power is equal to the rated energy, i.e., the storage is fully charged each day, i.e., $E_t^{ch} = E^{\max}$.

- Therefore

$$LCOE = \frac{(CC^{P} + CC^{E} T^{ch}) + \rho T^{ch} T}{\eta T^{ch} T}$$

- The LCOE of the energy storage only depends on its annualized power and energy investment costs, the charging time, the roundtrip efficiency, and the utility grid price.

- This LCOE does not depend on the energy storage size, similar to the LCOE of generation units which is independent of their size.

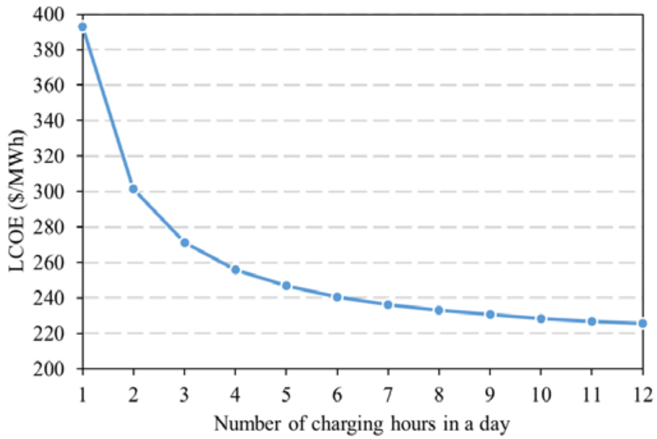
- The only external factor is the utility grid price which explicitly shows that the LCOE of the energy storage is highly dependent on its installation location.

Numerical Results

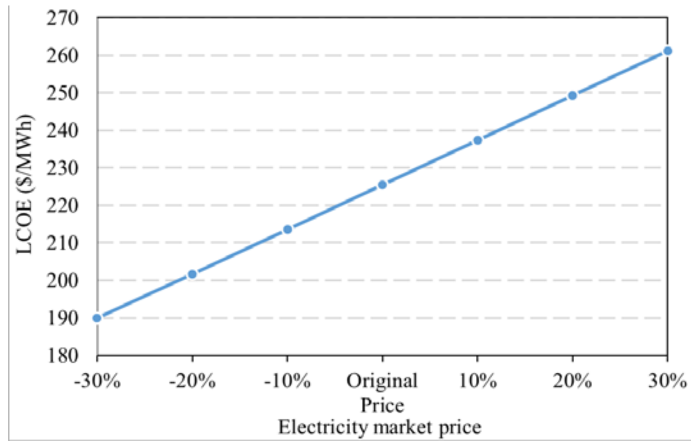
- The data of energy storage used for numerical calculations are represented below
- The energy storage efficiency and the average electricity price are considered to be 90% and $107.1/MWh, respectively
- It is assumed that the energy storage is charged with the maximum capacity in half a day and discharged in the other half. Therefore, the charging/discharging time would be 12 hours.

Allowable Installation Capacity (MW)	Allowable Installation Energy (MWh)	Annualized Investment Cost – Power ($/MW)	Annualized Investment Cost – Energy ($/MWh)
1	12	60,000	30,000

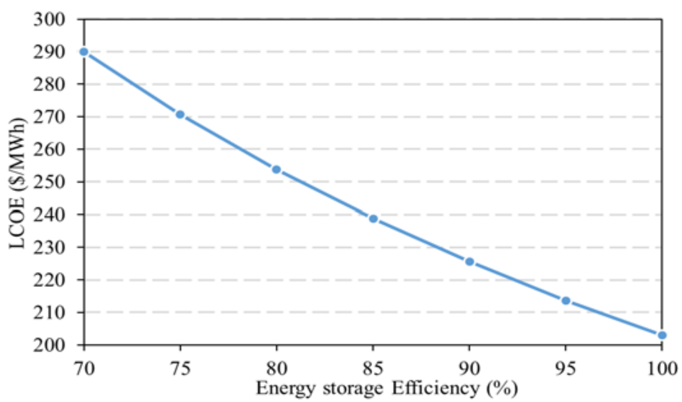
- Considering the above data, the LCOE of energy storage would be computed as $225.55/MWh.



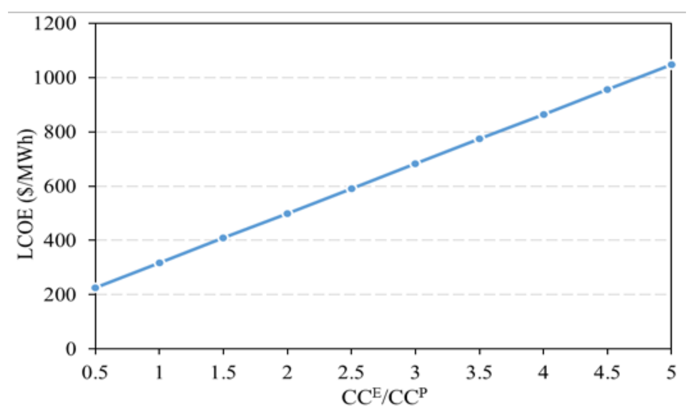
Number of charging hours in a day



Electricity price

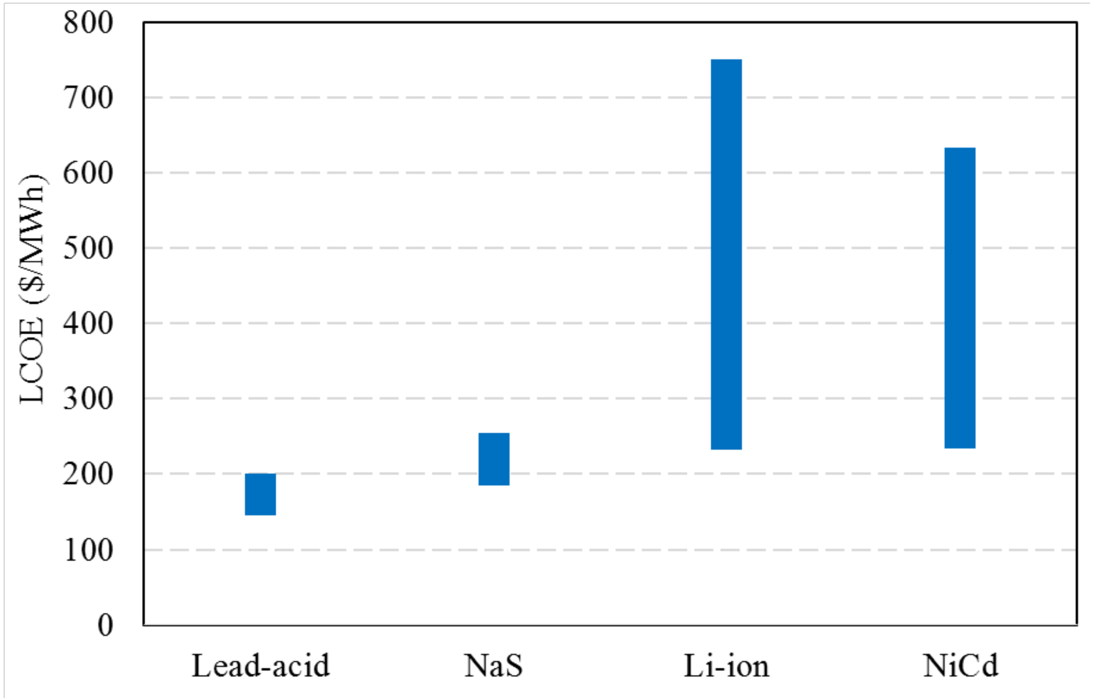


Efficiency



Ratio of IC of energy to power

- The range of LCOE values of four common types of energy storage are shown
- The amounts of LCOE were calculated based on 12h charging hours in a day and an electricity price of $107.1/MWh.
- The obtained results show that lead-acid and NaS technologies have the lowest LCOE, compared to other commonly-used technologies, i.e., Li-ion and NiCd.



Thank you

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